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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04R 3/04 // 3/00

A1

(11) International Publication Number: WO 97/42789

(43) International Publication Date: 13 November 1997 (13.11.97)

(21) International Application Number: PCT/IB97/00487

(22) International Filing Date: 5 May 1997 (05.05.97)

(30) Priority Data:
96201263.9 8 May 1996 (08.05.96) EP
(34) Countries for which the regional or international application was filed: NL et al.

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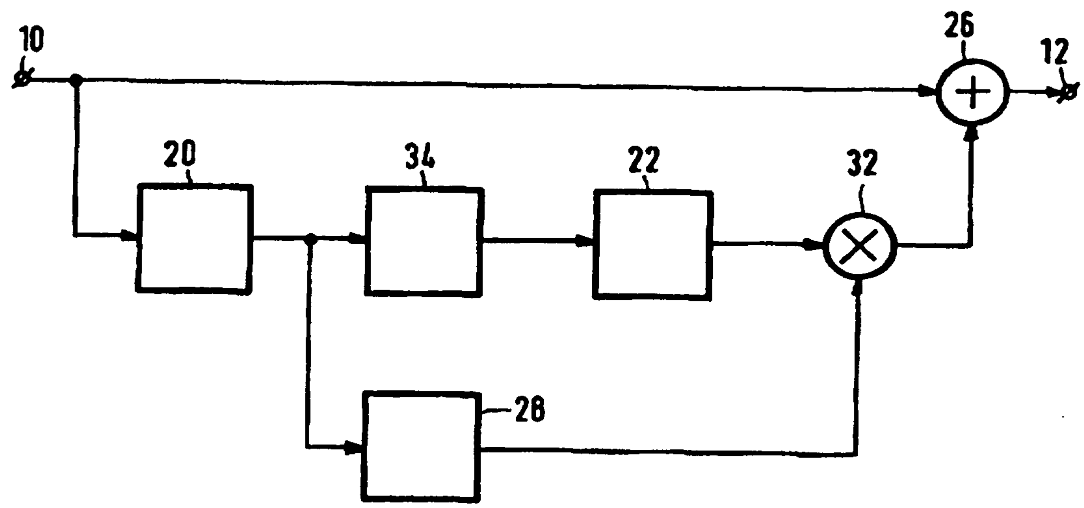
(81) Designated States: CN, JP, KR, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: CIRCUIT, AUDIO SYSTEM AND METHOD FOR PROCESSING SIGNALS, AND A HARMONICS GENERATOR



(57) Abstract

A circuit, audio system and method are presented for processing an audio signal, in which a frequency band is selected, harmonics are generated from the selected signal by a harmonics generator, wherein the harmonics are scaled by a level detected in at least a part of the spectrum of the audio signal related to the selected frequency band. Furthermore, a harmonic generator is presented for generating arbitrary harmonics of an input signal.

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Circuit, audio system and method for processing signals, and a harmonics generator.

The invention relates to a circuit for processing an audio signal, comprising:

- an input for receiving the audio signal and an output for supplying an output signal,
- selecting means coupled to the input for selecting a frequency band of the audio signal,
- harmonics generator coupled to the selecting means for generating harmonics of the selected signal,
- adding means coupled to the input as well as to the harmonics generator for supplying a sum of the input signal and the generated harmonics to the output.

The invention also relates to an audio reproduction system comprising such a circuit.

The invention further relates to a method for processing an audio signal, comprising the steps of:

- selecting a frequency band of the audio signal,
- generating harmonics of the selected signal,
- supplying a sum of the audio signal and the generated harmonics.

A circuit according to the preamble is known from EP-A 546 619. In the known circuit a low frequency band of an input signal is selected and supplied to a harmonics generator for generating harmonics of the selected signal. In this way low-frequency perception of the audio signal is improved upon. In the known circuit a full wave rectifier is used as harmonics generator. A drawback of the full wave rectifier is that it generates only even harmonics.

An object of the invention is to provide a circuit for processing an audio signal, wherein any non-linear device may be used as harmonics generator for generating any

selection of harmonics desired.

A circuit according to the invention is characterized in that the circuit further comprises:

- detecting means for detecting a level of at least a part of the spectrum of the audio signal including the selected frequency band,
- scaling means for scaling the generated harmonics in response to said level.

The invention is based on the recognition that in the prior art the full wave rectifier only produces even harmonics having a fixed amplitude relation with the fundamental harmonic. Through the measures of the invention any non-linear device can be used as harmonics generator, thereby allowing the freedom to generate any combination of odd and even harmonics and its amplitude relation to the fundamental harmonic. However, the use of any arbitrary harmonics generator will result in a different low-frequency perception at low input signals compared to high input levels. This is caused by the fact that in a non-linear device, such as a diode, the generated harmonics have amplitudes, which are non-linearly related to the amplitude of the fundamental harmonic, whereas the amplitudes of the harmonics generated by the full wave rectifier are linearly related to the amplitude of the fundamental harmonic. By using the measure according the invention the generated harmonics can be scaled properly, thereby allowing the freedom of choice of using any non-linear device as harmonics generator, without a level-dependent low-frequency perception.

An embodiment of the circuit according to the invention is characterized in that the input is coupled to the adding means <u>via</u> a filter having a high pass transfer function for selecting frequencies higher than those which are selected by the selecting means. By this measure, no overlap in spectrum of the signals supplied to the adding means takes place, thus avoiding an extra and unnatural boosting of those frequencies, which would otherwise be present due to the overlap of frequency ranges.

An embodiment of the circuit according to the invention is characterized in that an input of the detecting means is coupled to an output of the selecting means. Through this measure the amplitude of the generated harmonics is directly related to the amplitude of the input signal of the harmonics generator. In addition to that, in this way the selecting means serves a double purpose, both for the detecting of the level and for selecting the signal for the harmonics generator. This results in a more economic circuit.

An embodiment of the circuit according to the invention is characterized in that the circuit comprises at least one further signal stage, coupled between the input and a further input of the adding means, the signal stage comprising:

- a further selecting means coupled to the input, having a selection characteristic for selecting a part of the input signal in frequency adjacent to the selected signal of the selecting means,
- a further harmonics generator coupled to the further selecting means for generating harmonics of the signal selected by the further selecting means,
- further detecting means coupled to the further selecting means for detecting a level of the by the further selecting means selected signal,
- further scaling means for scaling the by the further harmonics generator generated harmonics in response to said level.

By providing two (or more) parallel paths for generating harmonics, the effect of intermodulation is reduced. This intermodulation results if two or more strong low frequencies are present at the input of the harmonics generator. By selecting the pass bands of the selecting means sufficiently narrow and providing a plurality of harmonics generators, each supplied by respective selecting means having adjacent pass bands, the chances of two strong low frequencies present at the input of one of the harmonics generator is substantially reduced. By providing each individual signal path with its individual detecting means, the harmonics generated in each path will have an amplitude related to only the signal component from which the harmonics are generated. This results in a more natural sound.

An embodiment of the circuit according to the invention is characterized in that the harmonics generator comprises a plurality of cascaded multipliers, each having two inputs and an output, the inputs of the first of the cascade of multipliers being coupled to an input of the harmonics generator, a remaining input of each of the remaining multipliers being coupled to the input of the harmonics generator, an output of each of the multipliers being coupled via a coefficient to a respective input of further adding means, the input of the harmonics generator being coupled via a coefficient to an input of the adding means, the adding means further receiving a constant value, an output of the adding means supplying the generated harmonics.

Through this measure a versatile harmonics generator is created. By varying the number of multipliers and the values of the coefficients, an arbitrary number of harmonics can be generated with freely determinable amplitudes.

An embodiment of the circuit according to the invention is characterized in that the harmonics generator comprises a zero crossing detector and a wave form generator for generating a wave form in response to the detected zero crossings, an amplitude of the generated wave form being controlled by the level supplied by the detecting

means.

By dividing the harmonics generator into a zero crossing detector and wave form generating means, it is possible to generate harmonics on the basis of the detected zero crossings, with fixed amplitudes. By choosing the appropriate wave form it is possible to adjust the number and amplitudes of the harmonics. By controlling the amplitudes with the detected level, the generated harmonics are adapted to the audio signal.

An embodiment of the circuit according to the invention is characterized in that the wave form generator comprises a current source controlled by the level supplied by the detecting means, a capacitance and means for charging and discharging the capacitance in response to the detected zero crossings.

This is a simple and advantageous embodiment of a wave form generator for use in the invention.

An embodiment of an audio system comprising at least one speaker according to the invention is characterized in that the selected frequency band of the selecting means is non-overlapping with the high-pass characteristic of the speaker.

By this measure the circuit is adapted to compensate the low-frequency deficiencies of the speaker, as only those frequencies are treated by the circuit, which the speaker can not reproduce adequately.

A method according to the invention is characterized in that the method further comprises the step of scaling the generated harmonics in response to a level of at least a part of the spectrum of the audio signal including the selected frequency band.

The invention further provides a harmonics generator for generating harmonics of an input signal, comprising a plurality of cascaded multipliers, each having two inputs and an output, the inputs of the first of the cascade of multipliers being coupled to an input of the harmonics generator, a remaining input of each of the remaining multipliers being coupled to the input of the harmonics generator, an output of each of the multipliers being coupled via a coefficient to a respective input of further adding means, the input of the harmonics generator being coupled via a coefficient to an input of the adding means, the adding means further receiving a constant value, an output of the adding means supplying the generated harmonics. By selecting an appropriate number of multipliers and selecting appropriate values for the coefficients, it is possible to generate an arbitrary number of harmonics with individually selectable amplitudes.

The invention also provides a harmonics generator for generating harmonics of an input signal, comprising a zero crossing detector for detecting zero crossings

in the input signal applied to the harmonics generator and a wave form generator for generating a wave form in response to the detected zero crossings, an amplitude of the generated wave form being controlled by a level of the input signal.

This is a simple implementation of a harmonics generator. By generating a wave form in response to the detected zero crossings, harmonics are generated, which will have a constant amplitude. Now the scaling of the generated harmonics can be done by controlling the amplitude of the harmonics by the level of the input signal. In this way the amplitudes of the harmonics can be made proportional to the level of the input signal. By choosing the appropriate wave form (square/sawtooth/triangle etc.) the desired harmonics can be generated.

An embodiment of the harmonics generator is characterized in that the wave form generator comprises a current source controlled by the level supplied by the detecting means, a capacitance and means for charging and discharging the capacitance in response to the detected zero crossings.

This provides a simple way of generating the desired wave form in response to the detected zero crossings. These harmonics generators may also be used in the known circuit or even separately from this circuit or the circuits described previously.

The above object and features of the present invention will be more apparent from the following description of the preferred embodiments with reference to the drawings, wherein:

Figure 1 shows a known circuit for improving low-frequency perception,

Figure 2 shows a block diagram of a first circuit according to the invention,

Figure 3 shows an embodiment of a harmonics generator for use in the present invention,

Figure 4 shows a block diagram of a second circuit according to the invention,

Figure 5 shows a block diagram of a third circuit according to the invention,

Figure 6 shows a first embodiment of a wave form generator for use in the circuit of Figure 5,

Figure 7 shows a second embodiment of a wave form generator for use in the circuit of Figure 5,

Figure 8 shows diagrams of various wave forms a...h generated in response to a sinusoidal input signal applied to the zero crossing detector for use in the present invention,

Figure 9 shows a block diagram of a third circuit according to the invention,

Figure 10 shows a diagram of an audio system according to the invention.

In the figures, identical parts are provided with the same reference numbers.

Figure 1 shows a known circuit for improving low-frequency perception. The circuit comprises an input 10 for receiving an audio signal and an output 12 for supplying an output signal. The circuit further comprises selecting means 20 coupled to the input 10, a harmonics generator 22 coupled to the selecting means 20, a band pass filter 24 coupled to the harmonics generator 22, and adding means 26, coupled to the input 10 and the band pass filter 24, for supplying the sum of the audio signal and the output signal of the band pass filter 24 to the output 12. In EP-A 546 619, the selecting means 20 is a low pass filter, but it may also be a band pass filter for selecting a part of the frequency spectrum of the audio signal. The band pass filter 24 serves to eliminate any residual low and high frequency components, but is, however, not essential to the circuit. A full wave rectifier is used as a harmonics generator 22 for generating harmonics of a signal applied to its input. By inclusion of these harmonics in the audio signal, the impression of more low frequency content in the audio signal is given, thus giving an improved low-frequency perception. The harmonics generator 22 used in EP-A 546 619 only generates even harmonics. It is possible to replace the full wave rectifier by another non-linear device, which generates also uneven harmonics. A diode, for example, exhibits such non-linear behaviour. But now the impression of increased low-frequency content depends on the level of the audio signal.

Figure 2 shows a block diagram of a first circuit according to the invention. Compared with Figure 1 the following changes have been made:

- the band pass filter 24 is deleted,
- detecting means 28 are added, having an input coupled to an output of the selecting means 20,
- a divider 30 is inserted between the selecting means 20 and the harmonics generator 22, having an input coupled to an output of the selecting means 20 and an input coupled to an output of the detecting means 32, and an output coupled to the harmonics generator 22,
- a multiplier 32 is inserted between the harmonics generator 22 and the adding means 26, having an input coupled to an output of the harmonics generator 22,

a further input coupled to the output of the detecting means 28 and an output coupled to the adding means 26.

The detecting means 28 is a level detector for detecting a level of at least a part of the spectrum of the audio signal related to, or rather: including, the frequency band selected by the selecting means 20. This detected level may be a amplitude level, a power level, a peak level, an average level etc. The divider 30 together with the multiplier 32 constitute scaling means for scaling the generated harmonics in response to the detected level, supplied by the detecting means 28. By the inclusion of the detecting means and the scaling means according to the invention the abovementioned level-dependency of the low-frequency impression is substantially reduced. In the present invention it is namely recognised that this level-dependency is caused by the non-linear behaviour of the harmonics generator 22. For example, if the harmonics generator produces a second and a third harmonic of its input signal, this means also that the amplitude of the second harmonic will depend on the amplitude of the input signal to the second power. For the third harmonic, this dependency is to the third power. This means that the ratio of the amplitudes of the second and third harmonics is not constant, but a function of the amplitude of the input signal. Thus, at low signal levels the amplitudes of the generated harmonics will have a different relationship with the fundamental harmonic than at high signal levels. This explains that the low-frequency impression depends on the amplitude of the input signal. In the circuit of Figure 2, first the input signal to the harmonics generator 22 is normalized, i.e. made substantially amplitude-independent. This is done in the divider 30 by dividing an output signal of the selecting means 20 by the detected level supplied by the detecting means 28. Thus, the input signal of the harmonics generator 22 is normalized, i.e. made substantially level-independent. As a result of this, the amplitudes of the generated harmonics will always have substantially the same constant ratio. In multiplier 32, the harmonics supplied by the harmonics generator 22 are multiplied by the detected level supplied again by the detecting means 28. By making the generated harmonics again dependent on the amplitude of the input signal, the generated harmonics are brought in their proper amplitude relation with the audio signal. Preferably, the level of the input signal applied to the harmonics generator 22 is used for this scaling. However, this is not essential, as long as the harmonics are scaled in response to a level that is directly related to or includes at least a part of the audio signal. This means that the input of the detecting means 28 may also be coupled to the input 10, instead of the output of the selecting means 20. By using the measures of the invention, it is possible to use any non-linear device with the desired non-linear behaviour as harmonics generator, as the ratio of

the amplitudes of these harmonics will always be substantially independent of the input signal level. This freedom allows the choice of a harmonics generator 22, which generates any desired harmonics (odd and/or even) and its proper amplitude, in correspondence with the desired effect, and is no longer restricted to either a level-dependent low-frequency perception or a limited choice of generated harmonics (as generated by a full wave rectifier).

Figure 3 shows an embodiment of a harmonics generator for use in the present invention. The harmonics generator 22 comprises an input 210, an output 211, coefficients 221..225, a plurality of cascaded multipliers 201..203, each having two inputs and an output, and an adder 204. An input of each of the multipliers is coupled to an input 210 of the harmonics generator 22. A further input of multiplier 201 is also coupled to the input 210. The remaining inputs of multipliers 202 and 203 are coupled to the outputs of multipliers 201 and 202, respectively. Each of the outputs of the multiplier 203..201 is coupled via respective coefficients 221..223 to the adder 204. The input 210 is also coupled to the adder 204 via a coefficient 224. In addition to, that a constant value of 1 is also coupled to the adder 204 via a coefficient 225. The value of C5 is chosen so that no DC appears at the output of the adder 204. The coefficients 221..225 multiply their respective input signals with respective values C1..C5. By setting the coefficient values C1..C5 at their appropriate values, any mix of first to third harmonics can be generated accordingly. If more or less harmonics are required, the number multipliers and coefficients can be increased or decreased. By making the coefficients C1..C5 adjustable, the generated harmonics can be adapted in number and magnitude to achieve the required low-frequency effect or they can be adapted to the low-frequency imperfections of a speaker coupled to the circuit. The harmonics generator shown allows a free choice in number and amplitude of the harmonics generated.

Figure 4 shows a diagram of a second embodiment of a circuit according to the invention. Compared with Figure 2, the divider 30 is in effect and purpose replaced by an automatic gain control circuit 34 for normalizing the input signal of the harmonics generator 22 and the output of the detecting means 28 is now only coupled to an input of the multiplier 32. Automatic gain control circuits are generally known and need not be discussed in detail.

Figure 5 shows a diagram of a third embodiment of a circuit according to the invention. The circuit of Figure 3 comprises the selecting means 20 coupled to the input 10, the harmonics generator 22 coupled to the selecting means 20, the detecting means 28 coupled to the selecting means 20, the adding means 26 coupled to the input 10 and the

harmonics generator 22 for supplying a sum signal to the output 12. The harmonics generator 22 comprises a zero crossing detector 240 for detecting zero crossing in a signal supplied by the selecting means 20, and a wave form generator 241 for generating a wave form based on the detected zero crossings, the wave form having an amplitude related to the detected level supplied by the detecting means 28. Preferably, the amplitude of the waveform is made proportional to the detected level. For this purpose the wave form generator 241 is coupled to both zero crossing detector 240 and the detecting means 28. By generating a wave form in response to the detected zero crossings it is possible to generate harmonics having a predetermined and constant amplitude relation with each other. By selecting the appropriate wave form it is possible to select which harmonics are generated and which not, and even which amplitude relation there should be. For example, a square wave form only comprises odd harmonics of a predetermined magnitude, whereas a triangular wave form also comprises odd harmonics but with different magnitudes. However, a saw tooth wave form comprises both odd and even harmonics. By scaling the generated waveform in response to the detected level, the generated harmonics will fit in with the audio signal. Any conventional zero crossing detector can be used for the zero crossing detector 240, for instance a limiter etc. In case a limiter is used, the output signal of such a limiter would be a square wave with a period of 2 zero crossings. This output signal itself may be used as output signa of the harmonics generator 22, without passing it through a wave form generator 241. In this case block 241 may be replaced by a simple multiplier for adapting the amplitude of the output signal of the zero crossing detector 240 to the detected level.

Figure 6 shows a first embodiment of a wave form generator for use in the circuit of Figure 5. The wave form generator comprises a resistor 401, a main current path of a PNP transistor 402, a switch transistor 403 and a capacitor 404, placed in series. Parallel to the capacitor 404 a second switch transistor 405 is placed. The transistor 402 is biased with a voltage source 406 coupled to the base of the transistor. Transistors 403 and 405 function as switches, activated by signals CH and RST, respectively. The voltage source has a value of Vb+Vx, wherein Vb is a bias voltage and Vx is a voltage related to the detected level supplied by the detecting means 28. Resistor 401, transistor 402 and voltage source 406 constitute a current source, supplying a current proportional to the detected level through the main current path of transistor 402. When transistor 403 is activated by a charge signal CH, the capacitor 404 will be charged by the current supplied by transistor 402. When transistor 403 is deactivated, the charging of the capacitor 404 is stopped. By activating transistor 405 with a reset signal RST, the capacitor 404 is immediately discharged. The

signals CH and RST are derived from the zero crossing detector 240. The voltage across the capacitor has a wave form, comprising harmonics of the input signal of the zero crossing detector 240, and having an amplitude in response to the detected level. In the discussion of Figure 8, the signals CH and RST and the voltage Vx will be dealt with in more detail in connection with the shape of the wave forms generated.

Figure 7 shows a second embodiment of a wave form generator for use in the circuit of Figure 5. The wave form now comprises an operational amplifier 414, having its positive input grounded. A resistor 412, a capacitor 413 and a switch transistor 415 are placed in parallel with each other and couple the negative input of the operational amplifier 414 to its output. A voltage source 409 is coupled via a series circuit of switching transistor 410 and resistor 411 to the negative input of the operational amplifier 414. Switching transistor 410 receives the charging signal CH and switching transistor 415 receives the reset signal RST. The voltage source 409 has a value of Vx. Upon activation of transistor 410 with the charging signal CH, the capacitor 413 is charged with a current proportional to the detected level, and upon activation of transistor 413, the capacitor 413 is immediately discharged. The circuit of Figure 7 operates in a similar way as the circuit of Figure 6, but now the output of the operational amplifier supplies the generated harmonics, having an amplitude in response to the detected level.

Figure 8 shows diagrams of various wave forms a...h generated in response to a sinusoidal input signal applied to the zero crossing detector for use in the present invention. In these diagrams the solid lines depict the sinusoidal input and the dashed lines depict the styled wave forms generated by the wave form generator 241. $t_0..t_4$ are the moments the input signal goes through zero. In general, different wave forms can be generated depending on:

- different moments for resetting the capacitor voltage using the reset signal RST,
- different moments for charging the capacitor using the charge signal CH,
- the amplitude of the current as related to voltage Vx: the voltage Vx may for example be chosen to be proportional to the input signal (in this case the input signal and the output signal of the detecting means 28 differ only in amplitude), supplied to the zero crossing detector, or to the absolute value of said input signal (now the detecting means 28 comprises a rectifier). Other variants are also possible.

For the generation of the wave forms a...h of Figure 8, the signal CH may be constantly activated. This means that in that case transistors 403 and 410 may be replaced by short

circuits. For the wave forms a and b of Figure 8, a reset pulse RST is generated every second (t2, t4) and fourth (t4) zero crossing, respectively. For Figure 8e a reset pulse is generated at every zero crossing. This reset pulse RST is only a short pulse, generated at a moment the input signal goes through zero. For the wave forms c, d and f of Figure 8 no reset signal is required. In these cases transistors 405 and 415 may be deleted. For waveform h the reset pulse is generated every other crossing, but now either the reset pulse RST lasts until the next zero crossing or the charge signal CH is inactive every second zero crossing, lasting until the next zero crossing or both. In this latter case, the charge signal CH is the inverted reset signal RST. For waveforms a, b, f, g and h the voltage Vx is a function of the absolute value of the input signal supplied to the zero crossing detector 240. For waveforms c, d and e the voltage Vx is proportional to the value of the input signal, including its sign. The difference between waveforms e and c is that for waveform c no reset signal active, but for waveform e a reset signal is active at each zero crossing ($t_0..t_4$). For waveform h it does not matter whether Vx is a function of the value of the input signal or its absolute value as the charging of the capacitor only takes place during the same phase of the input signal. The wave form d of Figure 8 can be derived from the wave form c of Figure 8 in the following manner. The wave form c of Figure 8 is measured across the capacitor and this measured value then receives the sign of the input signal. This can be done by multiplying the measured value with a signal representing the sign of the input signal. Such a signal can be obtained directly at the output of a non-inverting limiter, which may serve as zero crossing detector 240. For generating the wave form f of Figure 8, the charging current of capacitor may be reversed in sign every second zero crossing. No reset signal RST is required. A signal for indicating the direction of the charging current may be obtained by dividing the signal representing the sign of the input signal (as described previously) by a factor 2. The generation of the previously described pulses for the reset signal RST lie well within the abilities of the skilled person and need not be explained in detail. The wave forms a...h of Figure 8 are only intended in an illustrative and not a limiting sense.

Figure 9 shows a diagram of a fourth embodiment of a circuit according to the invention. The circuit comprises a high pass filter 21 coupled to input 10, a plurality of band pass filters 20A..20N coupled to the input 10, a plurality of blocks 23A..23N coupled to the band pass filters 20A..20N, respectively, a plurality of further band pass filters 24A..24N, coupled to the blocks 23A..23N, respectively, outputs of the plurality of further band pass filters 24A..24N and the high pass filter 21 being coupled to the adding means 26. The blocks 23A..23N each comprise scaling means and a harmonics generator.

For example, a block may comprise the blocks 22 and 28 as shown in Figure 5, or the blocks 30, 22, 32 and 28 as shown in Figure 2, or even the blocks 34, 22, 32 and 28 as shown in Figure 4. The band pass filters 20A..20N preferably have band pass characteristics, that lie adjacent to each other. For example, band pass filter 20A may select frequencies from 20-30 Hz, band pass filter 20B may select frequencies from 30-40Hz etc. In this way, for each small frequency band selected by one of the band pass filters 20A..20N, harmonics are generated. An advantage of the division into small bands is, that less intermodulation distortion will occur during the generation of the harmonics. When no division takes place, it is possible that more than one strong low frequency component may be present at the input of the harmonics generator. The harmonics generator 22 will generate harmonics of not only these low frequency components, but also produce mixing products, wherein the low frequency components are mixed with each other. The harmonics generated from these mixing products are not present in the original audio signal and may be perceived as distortion. The division of the spectrum in small bands and assigning separate harmonics generators to each band will substantially prevent such intermodulation from taking place. The combined band pass filters 20A..20N thus select a part of the low pass spectrum of the audio signal. The high pass filter 21 preferably selects the high part of the spectrum of the audio signal, which is not selected by the band pass filter 20A..20N. In this way, no overlap between the frequency bands of the high pass filter 21 and the plurality of band pass filters 20A..20N is present, thereby avoiding an over-emphasis on the low frequency components in the output signal at output 12. The further band pass filters 24A..24N are similar in function as the band pass filter 24 shown in Figure 1. The band pass characteristic of one of the filters 24A..24N is chosen in correspondence with the band pass characteristic with an associated filter from the filters 20A..20N. When for example filter 20A has a band pass characteristic ranging from 20-30 Hz, then the characteristic of filter 24A may range from 20-120 Hz. Thus the upper cut-off frequency of filter 24A is preferably a multiple of the upper cut-off frequency of filter 20A. The same goes for the lower cut-off frequencies of these filters. It is not necessary for the lower cut-off frequencies of the filters 24A..24N to be equal to the lower cut-off frequencies of the filters 20A..20N. It is possible to use only one detecting means 28 to scale the harmonics in each block 23A..23N in response to the same detected level. However, it is preferable to use a separate detecting means for each block. The embodiments described here show a method for improving low frequency perception in an audio signal. By selecting a frequency band of the audio signal, generate harmonics of this selected signal and scaling the generated harmonics in response to a level

of at least a part of the spectrum of the audio signal, and supplying the sum of the audio signal and the harmonics as output signal, such a method is realised having all the benefits according the invention as described in relation with the embodiments of the invention as illustrated previously. The invention is of special advantage for audio reproduction systems, which comprise small speakers, for example portable radios, CD players, cassette recorders, or even television sets. By adding a circuit according to the invention, the perception of low-frequencies is improved upon.

Figure 10 shows a diagram of an audio system according to the invention. The audio system comprises a signal source 60 coupled to the circuit 61 for improving low-frequency perception, the circuit 61 being coupled to an amplifier 62, the amplifier 62 being coupled to a speaker 63. The signal source 61 may derive its signal from a CD, a cassette or a received signal or any other audio source. The circuit 61 can be any one of the circuits of Figures 2, 4, 5 or 9. The invention is particularly useful for use in conjunction with a speaker 63, which exhibits a high-pass characteristic. This means that low frequencies can not be reproduced adequately by the speaker 63. Preferably, the frequency band of the selecting means 20 of the circuit 62 is made non-overlapping with the high-pass characteristic of the speaker 63. Thus, harmonics are generated of only those frequencies which are attenuated by the speaker 63 or not even present in the acoustical signal produced by the speaker 63. The audio means may be a portable radio or CD player or any audio device comprising speakers which are limited in low-frequency reproduction, including even television sets with built-in speakers or multimedia PCs or even telephones. The order of circuit 61 and amplifier 62 can be reversed if desired. Furthermore, the audio system may include means for generating other sound effects etc., which are independent of and not material to the present invention.

The invention is by no means limited to the examples given above. For example, a band pass filter 24 may be incorporated also in the circuits of Figures 2, 4 and 5, directly before the adding means 26, similar as in Figure 1. Furthermore, instead of a direct coupling of the input 10 to the adding means 26, as shown in Figures 1, 2, 4 and 5, a high pass filter may be inserted, as shown in Figure 9. In addition to that, the harmonics generator is not limited to the example given. Other non-linear devices, such as diodes or transistors, may also be used to generate harmonics. The wave form generator is not limited to generating wave forms a...h as shown in Figure 8. A person skilled in the art will be able to realise other wave forms with other simple wave form generators as well, based on the detected zero crossings, such as square waves or more complex wave forms. Furthermore,

the harmonics generator shown in Figures 3 and 5 may also be used in the circuit known from EP-A 546 619 or even separately from such circuits.

CLAIMS:

1. A circuit for processing an audio signal, comprising:
- an input for receiving the audio signal and an output for supplying an output signal,
- selecting means coupled to the input for selecting a frequency band of the audio signal,
- harmonics generator coupled to the selecting means for generating harmonics of the selected signal,
- adding means coupled to the input as well as to the harmonics generator for supplying a sum of the input signal and the generated harmonics to the output,

characterized in that the circuit further comprises:
- detecting means for detecting a level of at least a part of the spectrum of the audio signal including the selected frequency band,
- scaling means for scaling the generated harmonics in response to said level.

2. The circuit of Claim 1, wherein the selecting means have a low pass transfer function, characterized in that the input is coupled to the adding means <u>via</u> a filter having a high pass transfer function for selecting frequencies higher than those which are selected by the selecting means.

3. The circuit of Claim 1 or 2, characterized in that an input of the detecting means is coupled to an output of the selecting means.

4. The circuit of Claim 5, characterized in that the circuit comprises at least one further signal stage, coupled between the input and a further input of the adding means, the signal stage comprising:
- a further selecting means coupled to the input, having a selection characteristic for selecting a part of the input signal in frequency adjacent to the selected signal of the selecting means,
- a further harmonics generator coupled to the further selecting means for generating harmonics of the signal selected by the further selecting means,
- further detecting means coupled to the further selecting means for detecting a level of the by the further selecting means selected signal,

- further scaling means for scaling the by the further harmonics generator generated harmonics in response to said level.

5. The circuit of Claim 1, 2, 3 or 4, characterized in that the harmonics generator comprises a plurality of cascaded multipliers, each having two inputs and an output, the inputs of the first of the cascade of multipliers being coupled to an input of the harmonics generator, a remaining input of each of the remaining multipliers being coupled to the input of the harmonics generator, an output of each of the multipliers being coupled via a coefficient to a respective input of further adding means, the input of the harmonics generator being coupled via a coefficient to an input of the adding means, the adding means further receiving a constant value, an output of the adding means supplying the generated harmonics.

6. The circuit of Claim 1, 2, 3 or 4, characterized in that the harmonics generator comprises a zero crossing detector and a wave form generator for generating a wave form in response to the detected zero crossings, an amplitude of the generated wave form being controlled by the level supplied by the detecting means.

7. The circuit of Claim 6, characterized in that the wave form generator comprises a current source controlled by the level supplied by the detecting means, a capacitance and means for charging and discharging the capacitance in response to the detected zero crossings.

8. An audio system, characterized in that the system comprises a circuit of Claim 1, 2, 3, 4, 5, 6 or 7.

9. The audio system of Claim 8 comprising at least a speaker having a high-pass characteristic, characterized in that the selected frequency band of the selecting means is non-overlapping with the high-pass characteristic of the speaker.

10. A method for processing an audio signal, comprising the steps of:

- selecting a frequency band of the audio signal,
- generating harmonics of the selected signal,
- supplying a sum of the audio signal and the generated harmonics, characterized in that the method further comprises the step of scaling the generated harmonics in response to a level of at least a part of the spectrum of the audio signal including the selected frequency band.

11. A harmonics generator for generating harmonics of an input signal, comprising a plurality of cascaded multipliers, each having two inputs and an output, the inputs of the first of the cascade of multipliers being coupled to an input of the harmonics

generator, a remaining input of each of the remaining multipliers being coupled to the input of the harmonics generator, an output of each of the multipliers being coupled via a coefficient to a respective input of further adding means, the input of the harmonics generator being coupled via a coefficient to an input of the adding means, the adding means further receiving a constant value, an output of the adding means supplying the generated harmonics.

12. A harmonics generator for generating harmonics of an input signal, comprising a zero crossing detector for detecting zero crossings in the input signal applied to the harmonics generator and a wave form generator for generating a wave form in response to the detected zero crossings, an amplitude of the generated wave form being controlled by a level of the input signal.

13. The harmonics generator of Claim 12, characterized in that the wave form generator comprises a current source controlled by the level supplied by the detecting means, a capacitance and means for charging and discharging the capacitance in response to the detected zero crossings.

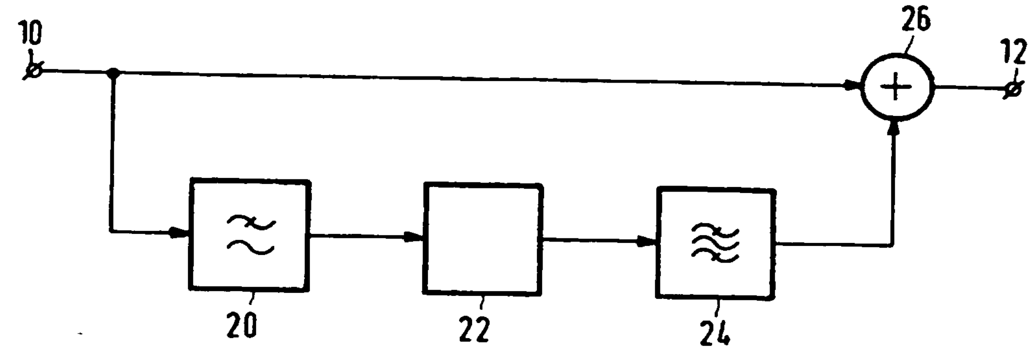


FIG.1

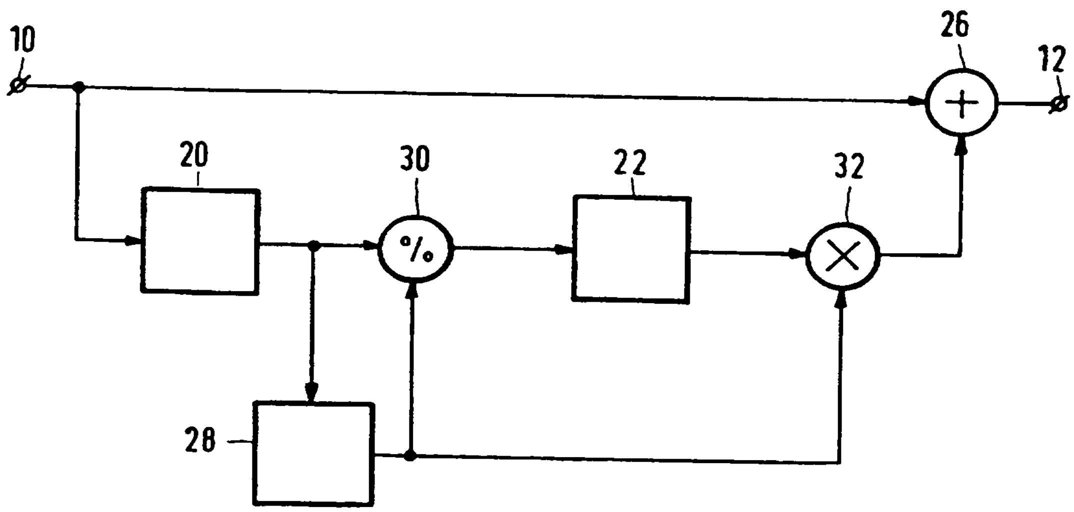


FIG.2

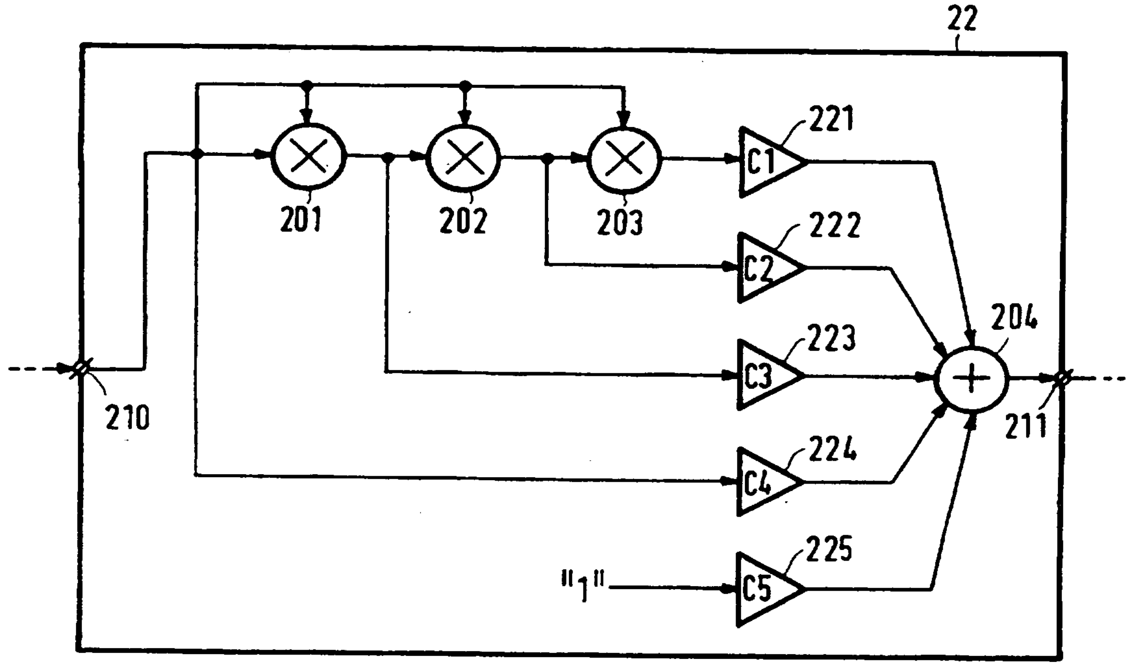

22
221
C1
201
202
203
222
C2
204
223
C3
210
211
224
C4
225
"1"
C5

FIG.3

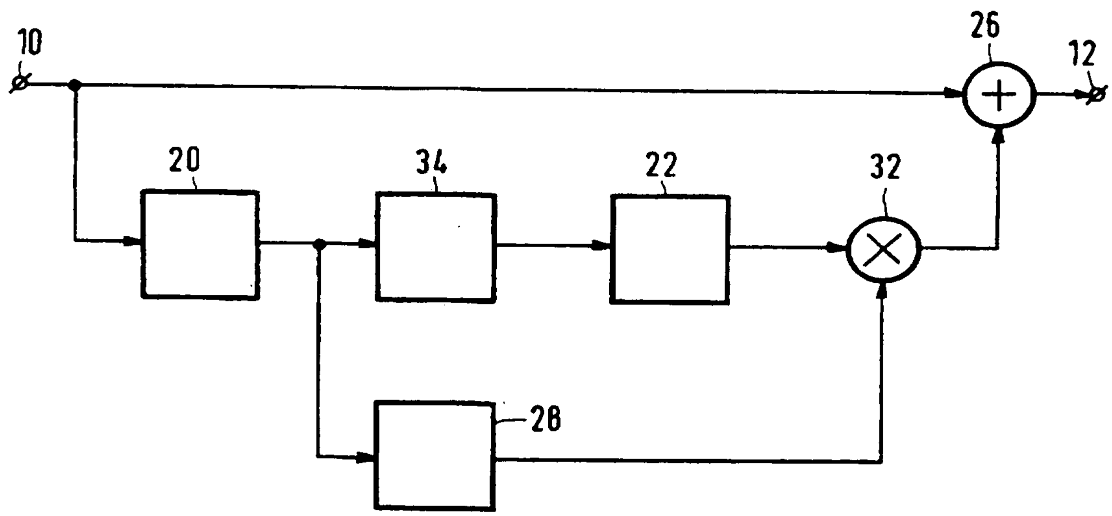

10
26
12
20
34
22
32
28

FIG.4

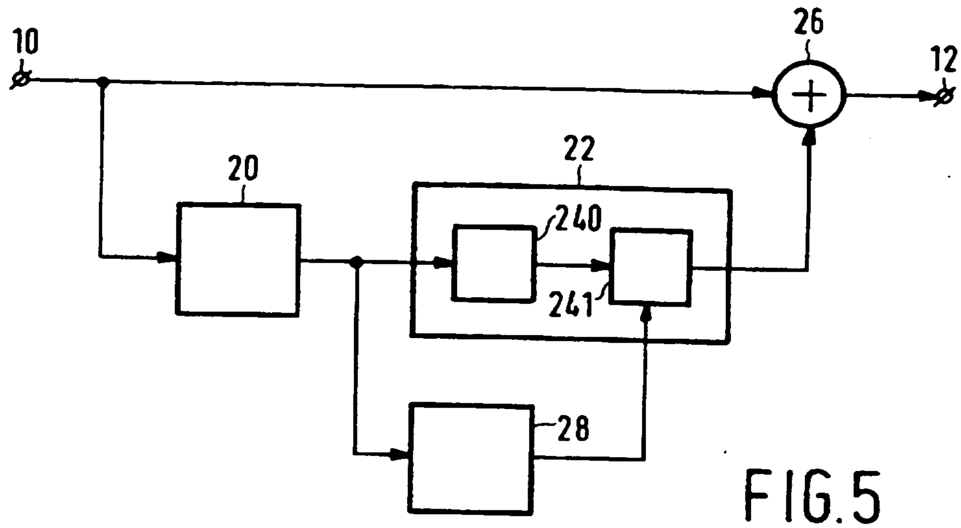


FIG.5

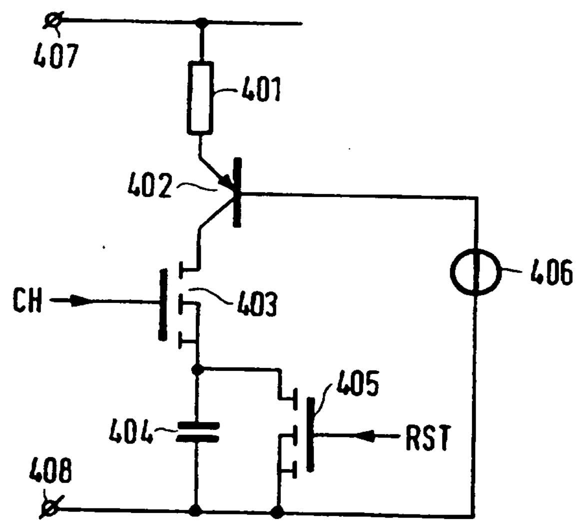


FIG.6

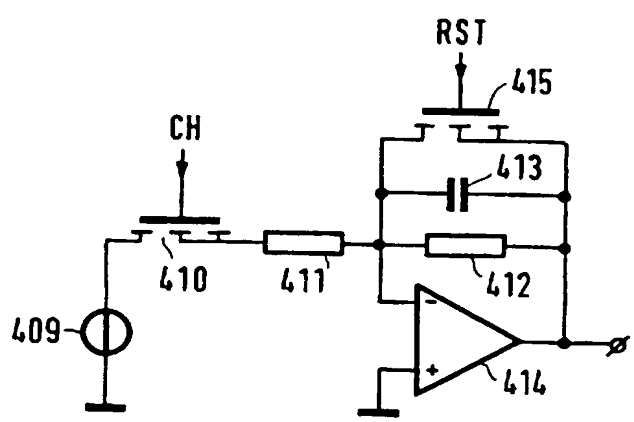
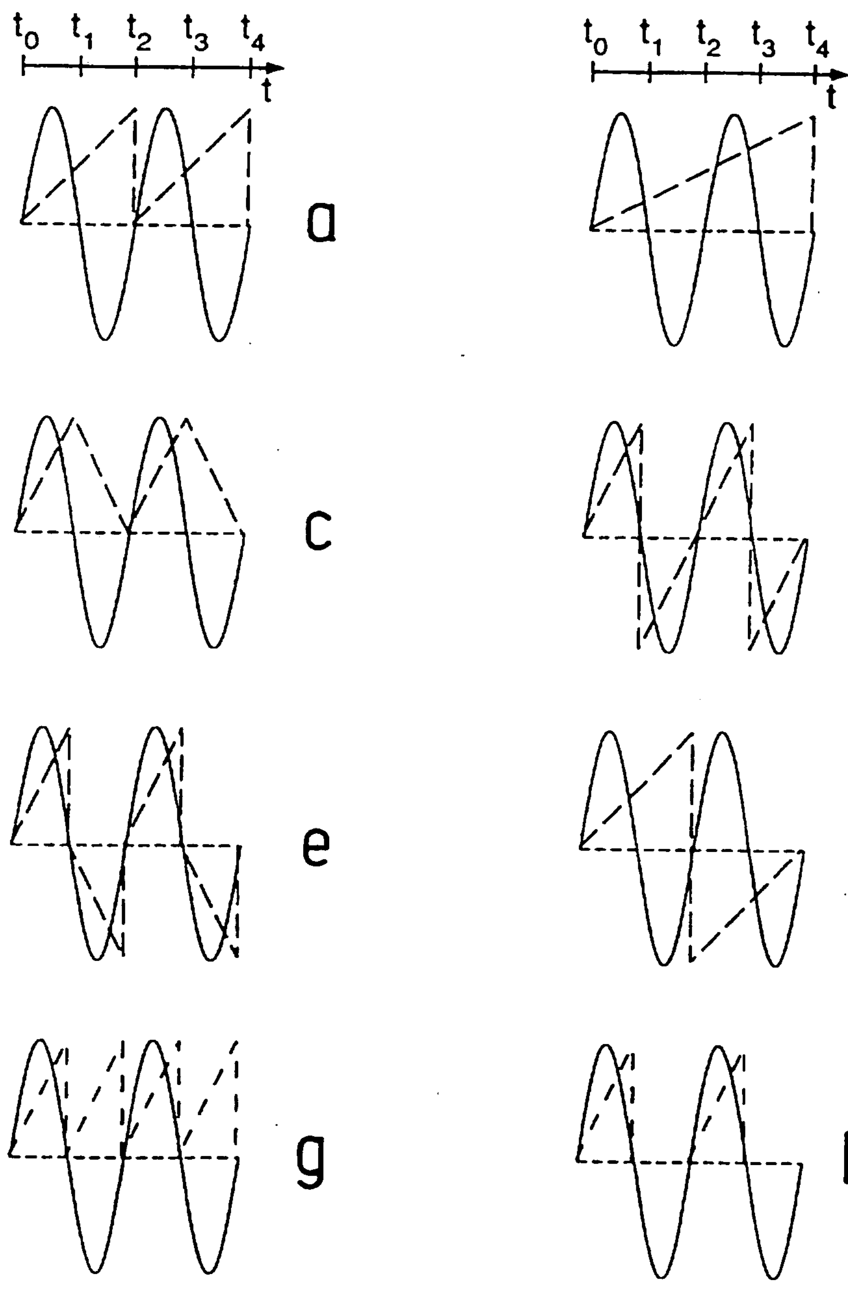


FIG.7



F IG.8

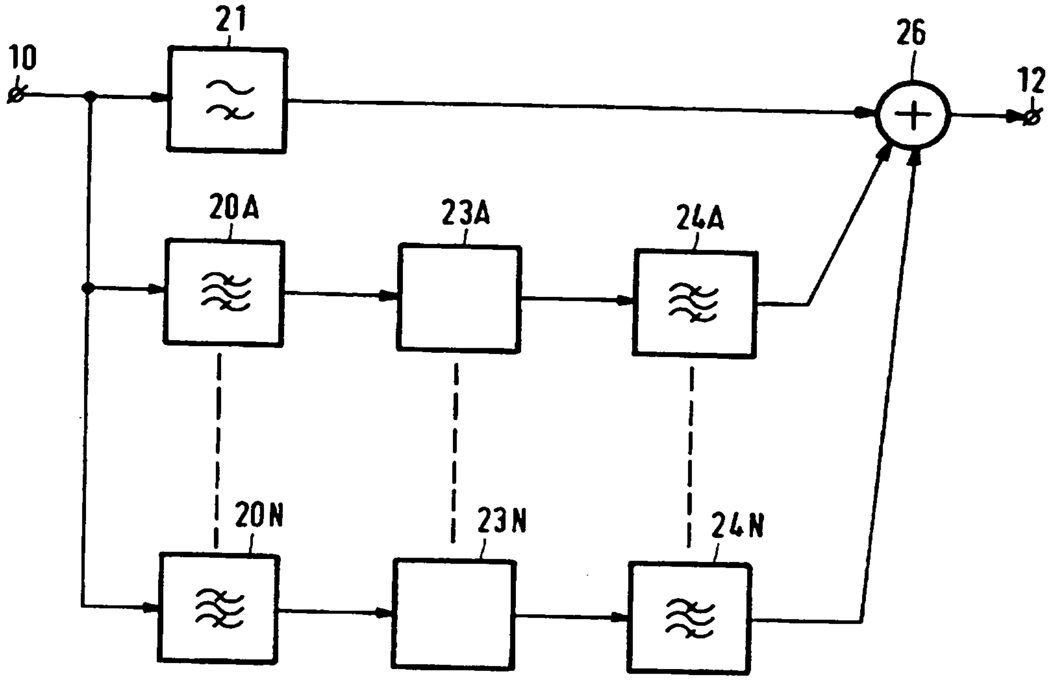


FIG.9

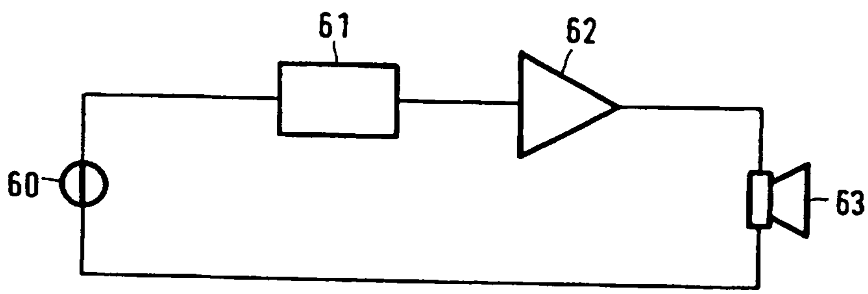


FIG.10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/00487

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04R 3/04 // H04R 3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 7231497 A ((VICO) VICTOR CO OF JAPAN), 29 August 1995 (29.08.95) --	1-13
A	EP 0729287 A2 (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.), 28 August 1996 (28.08.96) --	1-13
A	EP 0546619 A2 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN), 16 June 1993 (16.06.93) -- --------	1-13

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 August 1997	26 -08- 1997

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INTERNATIONAL SEARCH REPORT
Information on patent family members

06/08/97

International application No.
PCT/IB 97/00487

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 7231497 A	29/08/95	NONE	
EP 0729287 A2	28/08/96	CA 2170470 A	28/08/96
		CN 1135120 A	06/11/96
		JP 8237800 A	13/09/96
EP 0546619 A2	16/06/93	JP 5328481 A	10/12/93

Form PCT/ISA/210 (patent family annex) (July 1992)